Natural Regeneration of Swamp Black Spruce in Minnesota Under Various Cutting Systems

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By M. L. Heinselman[1]

Introduction

Black spruce (*Picea mariana* (Mill.) B.S.P.) is the most important pulpwood species in the coniferous swamps of Minnesota. Here it occurs on organic soils as a pure type. Natural regeneration is relied upon to replace stands that are cut. Over the years both even-aged and all-aged management systems have been advocated, but a comprehensive test of their effectiveness has not been reported.

In 1948 the Lake States Forest Experiment Station began a large-scale cutting study in swamp spruce in cooperation with the Minnesota Division of Forestry. The project is located on the Big Falls Experimental Forest north of Big Falls, Minn. There the regeneration and growth of black spruce are being tested under several cutting systems. This publication reports regeneration results 4 to 6 years after the initial cuttings. It is really a progress report on the study described by Neff (*17*).[2] Taken alone, the new data would permit only tentative conclusions because of the short period since logging. However, when the evidence is correlated with previous work at the Station and elsewhere, plus silvical information on the species, a pattern emerges.

Any silvicultural system must provide for satisfactory regeneration or ultimately it will fail. Of course, growth and yield of the stands, and costs and returns for the total operation are also crucial factors in choosing a cutting system. But economic decisions are only as sound as the biological information upon which they rest. This report is intended primarily as a contribution to silvicultural knowledge of the regeneration phase of swamp spruce management.

Study Area and Treatments

The experimental area is located on the clay plains of glacial Lake Agassiz. Soils are peats 1 to 5 feet deep, derived from mosses, wood, and other plants, and underlain by lacustrine silts and clays or lake-modified till. Surface peats are raw and acid (pH 3.5 to 4.5), but decomposition and pH increase with depth (i.e., *acidity decreases*

[1] The author is a research forester at the Grand Rapids, Minn., unit of the Lake States Forest Experiment Station, Forest Service, U.S. Department of Agriculture. A note of appreciation is due L. P. Neff, former Station staff member, now supervisor of the Superior National Forest, who planned the Big Falls study, and to other coworkers in the Station who aided in the research. Sincere appreciation is also expressed to the many members of the Minnesota Division of Forestry who cooperated on the project.

[2] Italic numbers in parentheses refer to Literature Cited, p. 21.

with depth). A road ditch provides artificial drainage, but most of the plots lie beyond its influence. Ground water is normally 6 to 30 inches below the surface. Before cutting, the ground cover under dense spruce was dominated by "feather mosses," chiefly *Calliergonella schreberi*,[3] *Hylocomium splendens*, and *Hypnum crista-castrensis*, with species of *Sphagnum*, *Dicranum*, and *Polytrichum* common but less abundant. *Ledum groenlandicum* (labradortea) was the chief shrub. On poorer sites and in open stands *Sphagnum* predominated, along with more bog shrubs including *Ledum*, *Chamaedaphne calyculata* (leatherleaf), *Kalmia polifolia* (bog laurel), and several species of *Vaccinium*. On some sites, sedges (*Carex*) and speckled alder (*Alnus rugosa*) were present. Spruce stands were pure and more or less even-aged, but age classes from 70 to 180 years existed. Site index for spruce (*7*) ranged from 30 to 60 feet at 100 years.

The experiment tests both even-aged and all-aged management. Design consists of 7 treatments repeated 3 times, making a total of 21 cutting compartments. Each compartment covers 6 to 9 acres, and is sampled by 8 to 16 growth plots. There are 10 permanent reproduction quadrats (milacres) per growth plot. Treatments are as follows (table 1):

1. Clear cutting in patches (even-aged management).

TABLE 1.—*Average stand data per acre by cutting system before and after logging, Big Falls Compartment Study* [1]

Cutting system	Before cutting			Cut			After cutting		
	Trees	Basal area	Volume	Trees	Basal area	Volume	Trees	Basal area	Volume
	No.	*Sq. ft.*	*Cds.*	*No.*	*Sq. ft.*	*Cds.*	*No.*	*Sq. ft.*	*Cds.*
Clear-cut strips.[2]	698	125	24	------	------	------	------	------	------
Clear-cut patches.[2]	780	119	20	------	------	------	------	------	------
Shelterwood	653	131	27	453	80	15	200	51	12
Group selection.	738	124	23	234	37	7	504	87	16
Tree selection	710	118	22	259	42	8	451	76	14
Light thinning.	861	132	23	276	36	6	585	96	17
Uncut (checks).	721	112	19	0	0	0	721	112	19

[1] Data include all trees 3.6 inches and up, d.b.h. There were 300 to 700 additional stems 1 to 3 inches in diameter. Volumes are to a 3-inch top, rough wood basis.

[2] On the clear-cut strip and clear-cut patch compartments all merchantable trees were cut within the strips and patches, but the remainder of the compartments were not cut at all.

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[3] *Calliergonella schreberi* has been placed in at least four other genera (viz., *Hypnum*, *Calliergon*, *Hylocomium*, and *Pleurozium*). Changes in nomenclature of the mosses are a source of confusion in the literature on spruce regeneration.

2. Clear cutting in strips (even-aged management).
3. Shelterwood (stand removal in two cuts, even-aged management).
4. Group selection (all-aged management).
5. Tree selection (all-aged management).
6. Light thinning (final harvest delayed).
7. Uncut (check area).

The clear-cut patches are ¼ to ½ acre in size. Strips are about 1 chain (66 feet) wide, and 6 to 10 chains long, oriented north-south. Approximately one-fifth of the area was cut in each of the patch and strip cuttings. No slash disposal was done, but a study of slash treatment on additional clear-cut strips was installed in 1954.

Precutting and postcutting tallies of reproduction by size classes were obtained. In the fall of 1954, four to six seasons after logging, the quadrats were again examined. Data were coded on keysort cards for: (1) stocking and count of reproduction by species, origin, size, and quality classes,[4] (2) site quality (*7*), (3) slash density, (4) shrub density, and (5) percentage of quadrat covered by skidroad. Spruce reproduction far outnumbered that of the few other species present.

Sources of Regeneration

Studies of spruce regeneration in swamps are complicated by the possibility of both vegetative and seedling reproduction (*8, 14, 19*) and by the frequent presence of advance growth. Persistent, semi-serotinous cones permit gradual seed dissemination throughout the year, and produce a seed supply in slash (*14*). Thus there are seven sources of natural regeneration:

1. Advance seedlings.
2. Advance vegetative reproduction (layers).
3. Seedlings from seed on the ground at the time of cutting.
4. Seedlings from seed in slash.
5. Seedlings from seed dispersed after cutting by trees left on or near the area.
6. Seedlings from seed borne by new stands when they attain seeding age—10 to 25 years (*8*).
7. Postcutting vegetative reproduction.

Earlier studies often are hard to evaluate because these sources were not separated. In this study they are distinguished whenever possible.

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[4] This study employs both "stocked quadrats" and trees per acre as estimates of regeneration success. A quadrat was recorded as stocked with a given class of reproduction if one or more such individuals existed in the milacre. An actual count of individuals by classes was also entered on the quadrat keysort card. In the analysis "stocking percentages" were obtained by simply calculating the percentage of the quadrats that were stocked. For example, if 48 quadrats out of 100 were stocked, the percentage would be 48—equivalent to 480 trees per acre if each stocked quadrat contained only one individual. In practice, uneven distribution of regeneration produces trees-per-acre figures well in excess of the corresponding stocking percentage. Thus stocked quadrats provide a more conservative estimate of restocking, and give more information on distribution.

Overstory Density

The most conspicuous difference between cutting systems is the degree of overstory removal. Factors that vary with overstories include heat, light, competition for moisture and nutrients, seed supply, and seedbeds. The interplay of these factors may create conditions favorable to one source of regeneration but unfavorable to others.

Most workers polled by Baker (*2*) rate black spruce as tolerant; yet in Minnesota well-stocked stands tend to be even-aged. There often are stems in the 1- to 3-inch diameter classes, but these usually are suppressed old growth. Many-aged or two-storied stands occur chiefly on poor sites where the stand is open, or on better sites where a decadent stand is breaking up. The widespread occurrence of even-aged forests of fire origin attests the ability of black spruce to reproduce in open areas (*11*, *15*, *16*). Late emergence of new growth in the spring (*8*) is a factor aiding survival on open swamplands where late frosts are so frequent.

One of the first trials of alternate clear-cut strips (*23*) produced 9,333 seedlings per acre in the cut strips and 12,762 beneath the stand 3 years later. All but 5.4 percent were of postlogging origin. The seedbed had been disturbed by collecting *Sphagnum*. An early study of the Lake States Station employed alternate 100-foot strips. Six years after logging there were 2,600 stems per acre in the open and 3,200 in the uncut strips. About half this reproduction was advance growth. Today, 21 years later, the cut strips are stocked with thrifty saplings, but regeneration in the uncut areas has not grown well.

Two tests of partial cutting in Minnesota gave stockings of 1,500 to over 3,000 stems per acre within a few seasons, but counts by origin classes were not reported (*14*, *21*). At Petawawa, Ontario, reproduction made better height growth on clear-cut swamps than in partial cuttings where 60 to 75 percent of the volume was cut (*3*). Both the clear-cut and partially cut areas had over 95-percent stocking 16 years after logging. Stocking of advance growth had been 88 percent or more in both cutting methods.

A survey of swamp cuttings near Big Falls (*5*) showed a consistent increase in regeneration with decreasing residual basal area on medium sites and "true peat good sites." Layers and advance origins were proportionately more common under heavy residual stands than on clear-cut areas. For uncut stands Schoenike and Schneider (*25*) also found an increase in reproduction with decreasing overstory. They report that 53 percent of "best specimens" were layers, which were most abundant on poor sites, in stands of low density, and in old stands. Even these "best specimens" often had only medium vigor.

Place (*20*) found seedlings beginning to appear at about 10 percent of full sunlight on somewhat dry uplands, but more light was needed for appreciable growth. On moist-to-wet sites he believed establishment possible either in the open or beneath all but the heaviest overstories.

Contradictions in the above literature might be resolved if more information were available. For example, on areas with clear-cut strips more reproduction was reported beneath the residual stands

than in the strips; yet regeneration surveys in older cut-over areas and in uncut stands show less beneath overstories. LeBarron's seedfall data [5] suggest that one might expect a greater initial catch of seedlings beneath an overstory if germination conditions are favorable. Establishment and growth must be distinguished from this initial catch of seedlings.

The Big Falls study permits a more rigorous test of the relation between overstory density and seedling establishment because counts were made by origin classes, a wide range of residual stands was available, clear-cut areas were small enough to assure seed fall, and there was replication. To test the relationship, residual basal areas were calculated on growth plots for all trees 1 inch and over in d.b.h. The stocking percentage for established [6] seedlings of post-cutting origin was then obtained for each plot. These data were averaged by 1-square-foot basal area classes. A correlation coefficient of $r = -0.882^{**}$ (**=significant at the 1-percent level) was obtained for the relation between stocking and residual basal area. Inspection of the means and regression line (fig. 1) shows that stocking increased quite consistently as basal area decreased. Thus complete or nearly complete overstory removal produced the most favorable environment for seedling establishment.

Stocking was more variable when based only on individual plots, without obtaining means by 10-square-foot basal area classes. The correlation then became $r = -0.458^{**}$. Scatter of plots was so erratic from 0 to 60 square feet that it seemed possible most of this correlation was due to decreases in stocking at higher basal areas. The correlation for the 0- to 60-square-foot range was a nonsignificant $r = -0.011$. Perhaps factors associated with overstory density became less crucial below about 60 square feet. Other possible causes are the spotty distribution of slash piles, and variations in distance from seed trees in the heavy cuttings.

The period since cutting is too short at Big Falls to answer some questions. Will the "established" seedlings in the all-aged systems develop into crop trees at the same rate as in the heavy cuttings of the even-aged systems? Will new seedlings continue to come in? Fortunately, an older project known as the "Section 18 plots" helps bridge this gap. These plots were installed in 1941 by the Minnesota Division of Forestry in cooperation with the Lake States Station. Two types of partial cuttings were employed that left residual stands similar to the all-aged systems at Big Falls. Reproduction transects were laid out near the edge of these partial cuttings and in a clear-cut area adjacent.

Now, 17 years after cutting, the development of reproduction is strikingly better in the clear-cut area (figs. 2 and 3) There are more than 1,100 stems per acre over 5 feet tall in the clear-cut area, but

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[5] LeBarron (*11*) found that annual seed fall near a clear-cut area declined from 300,000 seeds per acre within the stand to 19,000 at 100 feet, and almost none beyond 300. On strips 100 feet wide, seed fall ranged from 240,000 per acre in the stand edge to 80,000 per acre in the center (*14*).

[6] "Established" seedlings include only those classified as in good vigor, and 2 or more years old.

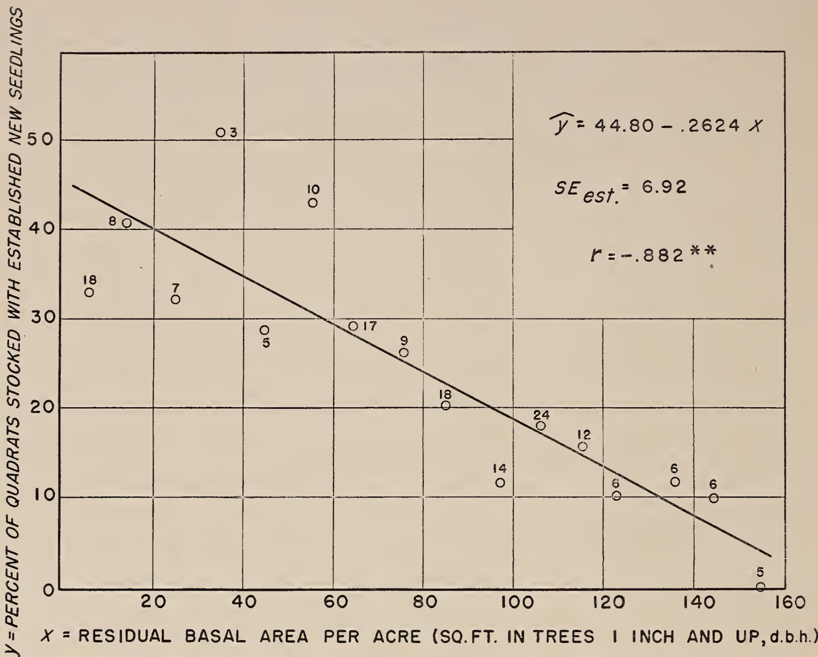

FIGURE 1.—Relation of residual basal area to stocking of established black spruce seedlings of postcutting origin, 4 to 6 years after logging on the Big Falls compartment study. (Plotted points are means by 10-square-foot basal area classes. Numerals indicate number of plots upon which each mean is based. **=significant at the 1-percent level.)

none over 5 feet in the partial cutting (table 2). In the partially cut area 85 percent of the stems are still less than 6 inches tall. Many are new seedlings and layers that replaced others that died. Thus the reproduction beneath this residual stand is not making appreciable growth, and even survival is jeopardized. Reproduction increased gradually for the first 10 years, but since the 10-year counts there was a decrease of 400 to 600 stems per acre on the clear-cut transects and 1,400 per acre in the partial cutting. Only a slight drop in stocked quadrats resulted.

If one weighs the evidence, the effect of overstories on seedling establishment seems to add up to the following:

1. The initial catch of seedlings may be good either in the open or beneath a moderate overstory, provided seed is available.

2. Subsequent survival and height growth are much superior in the open.

3. The overstory level that can be tolerated for several years without serious loss of vigor probably does not exceed 40 or 50 square feet of basal area per acre.

4. Any cutting system must provide a seed source within seeding range of the area to be regenerated, unless advance growth is adequate. Either a residual stand within about 100 feet (as in strip

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FIGURE 2.—Poor development of regeneration 17 years after a moderate partial cutting, Section 18 plots. Observer stands behind the best specimens. Note much larger stems in the clear-cut area in the background. (See also fig. 3 and table 2.)

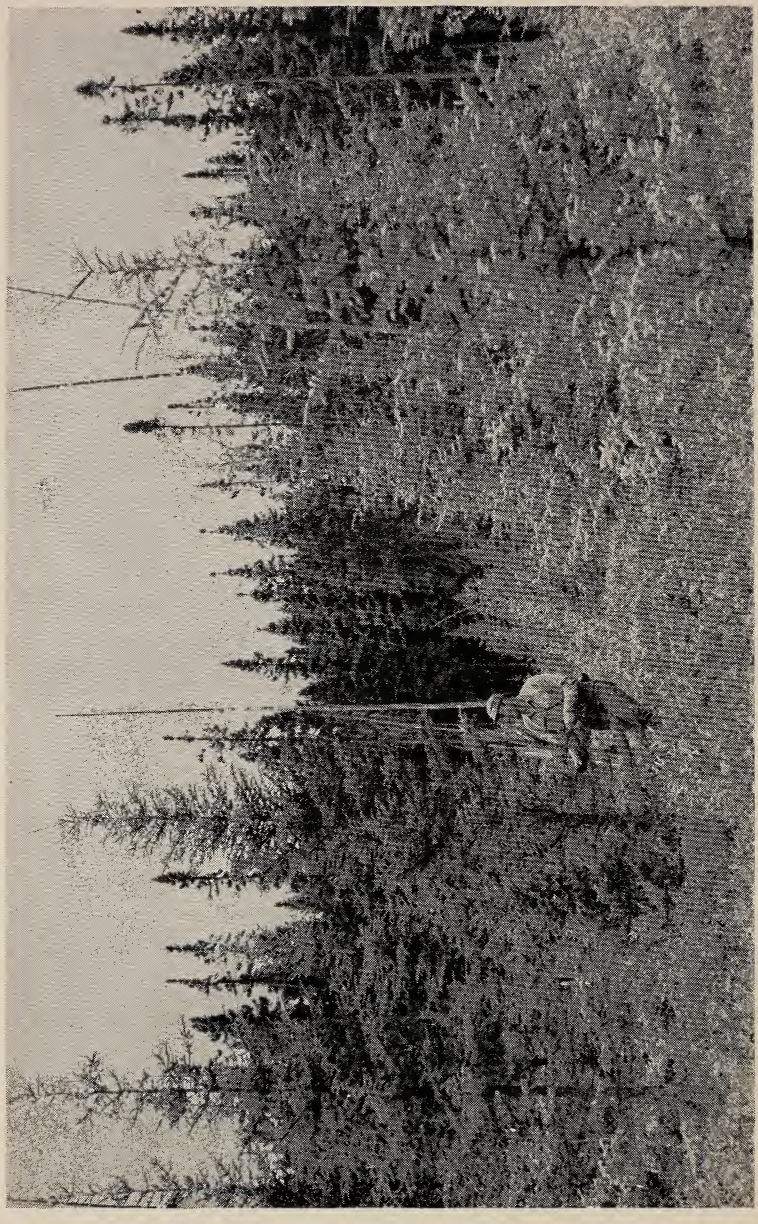

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FIGURE 3.—Development of regeneration 17 years after clear-cutting, Section 18 plots. Tallest stems are 15 to 20 feet. Residual stand left after partial cutting is in background.

TABLE 2.—*Stocking (trees per acre) and height of black spruce reproduction 17 years after cutting in relation to overstory*[1] *(Section 18 plots)*

Advance growth and reproduction	Moderate overstory	No overstory: Nearest overstory 100 feet from stand	No overstory: Nearest overstory 400 feet from stand
	Number	*Number*	*Number*
Advance growth after cut, 1941	2, 547	1, 387	1, 110
Reproduction by height class 17 years after cutting, 1957:			
Less than 6 inches	3, 122	143	70
1–5 feet	545	2, 162	1, 730
6–10 feet	0	857	920
11–15 feet	0	255	250
16–20 feet	0	20	70
Total (includes some advance growth)	3, 667	3, 437	3, 040
	Percent	*Percent*	*Percent*
Stocked quadrats, 1957	71. 7	83. 7	76. 0

[1] The moderate stand occurred in a light partial cutting where about 90 square feet of basal area in trees 4 inches and up had been left. The other two reproduction transects were in a clear-cut area just east of this partial-cut stand. Basis for data: 90 permanent milacres in the moderate stand; 98 and 100 milacres respectively for transects in the open.

or patch cutting) or a light overwood of seed-bearing trees (a shelterwood) will accomplish this.

5. If a shelterwood is left, it appears that reproduction will make the best growth if this overstory is clear cut as soon as a catch of seedlings is obtained.

Seedbed Factors

Laboratory germination of black spruce seed averages 61 percent (*27*). Dormancy is not common, and it is unlikely that many viable seeds remain in the duff over one season. The primary rootlets penetrate about ½ inch within a week of germination, but only 1 or 2 inches by the end of the first year (*12*). Germination studies on natural seedbeds by Place (*20*) gave 30 percent on *Sphagnum*, 15 percent on *Dicranum*, 7 percent on *Calliergonella*, and 6 percent on litter in a dry year.

At Big Falls at least 80 percent of the peat surface was moss covered before cutting. The moss carpet is 2 inches or more thick, and is the major seedbed. Feather mosses grow best in heavy shade, and often die out and dry up after exposure by clear cutting (*4, 12, 20, 26*). Some *Dicranums* also react in this fashion, but several of the *Sphagnums* grow well in the open. Thus the area occupied by *Sphagnum* tends to increase after cutting. These floral changes could be due to altered ground-water levels and soil moisture as well as to increases in light intensity and heat.

Seedbeds were investigated in a supplemental study of slash on clear-cut strips. In the spring of 1954, just after logging, only 2 percent of the quadrats were stocked with seedlings, but by the fall of 1956, three seasons after cutting, many new seedlings had come in. A tally by seedbeds showed the following occurrence of black spruce seedlings on clear-cut strips:

Seedbed type:	*Area occupied (percent)*	*Total seedlings on area* [1] *(percent)*
Sphagnum	43. 1	93. 3
Feather mosses and *Dicranum* [2]	39. 0	2. 2
Raw litter	14. 1	0
Burned duff	1. 7	3. 5
All others	2. 1	1. 0
Total	100. 0	100. 0

[1] Basis: 180 milacre quadrats. "Total seedlings" includes all age classes, but most were either 2 or 3 years old.
[2] Much of the feather moss and *Dicranum* was dead.

It is striking that 93 percent of the seedlings occurred on *Sphagnum*. despite the fact that only 43 percent of the area was in these mosses. Few seedlings survived on feather mosses, litter, or *Dicranum*. Better germination and survival on *Sphagnum* seedbeds than on the other mosses or litter are attributed largely to more dependable moisture on *Sphagnum*. Other factors may also be involved (*20*).

Over half the feather mosses and much of the *Dicranum* were already dead three seasons after logging, but whether living or dead they made poor seedbeds (*9*). Litter was mostly needles and twigs remaining beneath slash piles. Burned duff occurred where slash was burned in windrows. Little duff was consumed because snow remained under the slash, but these limited data suggest that burned duff is as good a seedbed as *Sphagnum*. Several more recent trials of slash burning on clear-cut strips and patches at Big Falls tend to confirm the favorable qualities of burned duff and burned peat seedbeds. However, in the very dry spring of 1958 both *Sphagnum* and burned duff surfaces gave little success.

Not all *Sphagnum* is favorable, even when moisture is adequate. LeBarron (*14*), Roe (*22*), and Place (*20*) point out that *Sphagnum* can outgrow seedlings and smother them. Several species occur, and differences in their growth rates and ecological requirements may be involved. *S. magellanicum* and *S. papillosum* are robust rank-growing mosses that often form deep loose mats. Smaller types apparently make favorable media for seedlings under some conditions. In the Big Falls study, regeneration on *Sphagnum* was so prompt that many seedlings quickly outgrew this threat of moss encroachment. Within 4 or 5 years after cutting, much of the *Sphagnum* develops into deep cushions that hinder establishment.

Skidroads are especially favorable for seedlings because they are slash-free, and because disturbance and compaction of peat and moss improve the seedbed. On the compartment study, where no slash disposal was done, stocking of new seedlings bore a close relation to the proportion of the quadrat occupied by skidroads (table 3). Layers, most of which were advance growth, followed a reverse trend because of skidding losses. On clear-cut strips and patches the skidroads occupied 10 to 25 percent of the area.

TABLE 3.—*Stocking of black spruce reproduction in relation to disturbance of peat and moss on skidroads*

Reproduction origin and intensity of cutting [1]	Stocking where percent of quadrat occupied by skidroads is—			
	0	1–30	31–60	60+
Established new seedlings:	*Percent*	*Percent*	*Percent*	*Percent*
Heavy	28. 2	64. 5	73. 3	86. 7
Light	13. 7	30. 2	47. 5	36. 8
Layers:				
Heavy	18. 5	13. 2	11. 1	10. 0
Light	26. 2	13. 2	10. 0	21. 0
All origins:				
Heavy	45. 1	73. 7	77. 8	91. 7
Light	39. 2	41. 5	52. 5	65. 8

[1] Heavy cutting includes clear-cut strips and patches, and shelterwood; light cutting includes all others.

Advance Growth

Uncut stands often have small seedlings and layers of varying ages despite competition from the overstory. At Big Falls stocking in trees less than 1 inch d.b.h. ranged from 28 to 53 percent for the 7 treatments before cutting. But averages do not tell the whole story. Of 21 compartments, there were 7 with advance stocking of 25 percent or less (only 9 percent on 1), 6 with 26 to 50 percent, 7 with 51 to 75 percent, and 1 with 92 percent. These figures are for areas of 6 to 9 acres, sampled by 80 to 160 well-distributed milacres.

The history of this advance growth is summarized in table 4.

TABLE 4.—*Stocking of advance growth by cutting system, in relation to logging damage and time since cutting*

Cutting system	Quadrats stocked with advance growth			
	Before cutting [1]	Lost in logging	Just after cutting	4 to 6 years after cutting
	Percent	*Percent*	*Percent*	*Percent*
Clear-cut strips and patches	46. 4	17. 2	29. 2	25. 6
Shelterwood	30. 7	7. 7	23. 0	17. 3
Group selection	28. 0	10. 4	17. 6	14. 8
Tree selection	46. 0	13. 0	33. 0	29. 7
Light thinning	31. 2	7. 5	[2] 23. 8	[2] 31. 5
Uncut	53. 4	------------	------------	[3] 46. 5

[1] Data from Neff (*18*).
[2] Difficulties in aging reproduction account for discrepancy between figures; the figure for 4 to 6 years since cutting is probably too high.
[3] For the uncut compartments, advance growth means stems present at time of the original counts.

Logging destroyed the stocking on 24 to 37 percent of the quadrats, or 21 to 57 percent of the stems (*18*). Losses were heaviest on the clear-cut areas. Four to six years later a further decline was found in most compartments. If one considers 60-percent stocking a minimum, none of the compartments was fully stocked with advance growth 4 to 6 years after cutting. Of the 9 heavily cut compartments, 3 had less than 20-percent stocking of advance growth.

Before cutting there were an additional 300 to 700 stems per acre 1 to 3 inches in diameter—mostly suppressed old growth. Logging destroyed 18 to 34 percent of these trees.

At Big Falls 86 percent of the advance stems left 4 to 6 years after logging were of layer origin. Only 28 percent of these layers were judged to be thrifty and to have reasonably good form, while 66 percent of the advance seedlings were so classified. Layers remain something of an enigma. When small they do not look promising, yet some unquestionably make good trees. Because of their tie to the parent they occur in clumps. No studies are known to have determined what percentage ultimately make acceptable trees, but work on this question appears to be needed.

The survey of advance growth by Schoenike and Schneider (*25*) found stockings of 41 to 76 percent in uncut stands. Lightest stocking was in dense stands on good sites, heaviest in open stands on poor sites. This was also the case at Big Falls, but most of the compartments were in well-stocked stands on medium-to-good sites. Studies already cited in which advance growth played an important role in restocking include Berry and Farrar (*3*) and Buckman and Schneider (*5*). Advance growth serves as an adjunct to postcutting seedling reproduction, but its variability demands caution in relying on this source alone. In general, advance stocking is greatest on poor sites and in understocked stands, and least on good sites and in dense stands.

Slash

Slash influences restocking by altering seedbeds and burying advance growth. On light partial cuttings there is no problem, but a large amount of slash is generated when heavy stands are clear cut. On clear-cut strips at Big Falls, 42 percent of the quadrats had more than 60-percent slash cover immediately after logging. Needles and twigs soon fall, but they create a layer of debris that becomes very dry even in short droughts. Disappearance of litter and of tops and limbs is slow. Four to six years after logging more than half the quadrats in the heavy cuttings still had at least a 20-percent slash cover, and one quarter still had more than 40-percent slash. In time *Sphagnum* may overgrow the litter, and even engulf some tops before decay occurs. On the Section 18 plots slash had disappeared in the clear-cut area after 17 years, but tops could still be found just beneath the moss.

On the heavy cuttings at Big Falls, a close relation was found between stocking of established new seedlings and degree of slash cover (fig. 4). The result was patchy regeneration, with failed spots beneath the slash piles. When all origins are included, stocking was greater, but there still was less reproduction in the slash areas. In

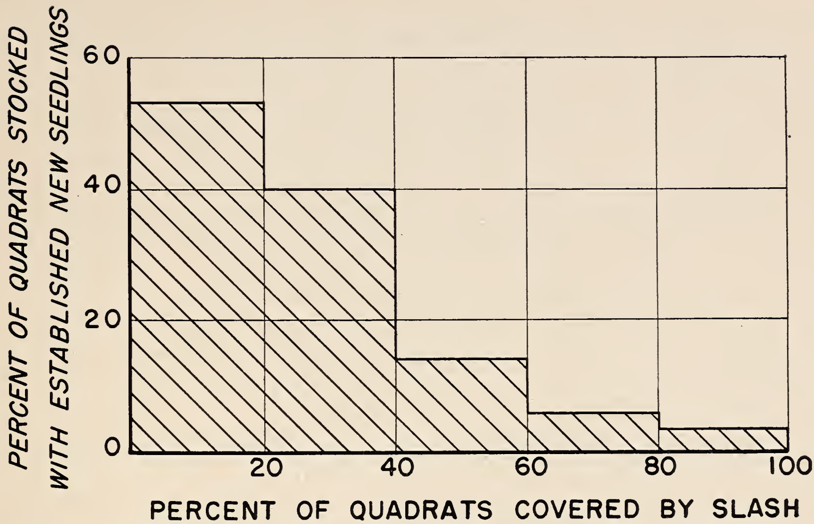

FIGURE 4.—Establishment of black spruce seedlings after heavy cutting in relation to slash density 4 to 6 years after logging. (Data include clear-cut strips and patches, and shelterwood systems. Basis, 780 milacres.)

the light partial cuttings there also was poorer stocking on quadrats with heavy slash, but only 10 percent had more than a 40-percent slash cover 4 to 6 years after cutting.

Slash disposal is a logical tool for improving seedbed conditions. At Big Falls slash was most concentrated on clear-cut strips, because the cutters windrowed slash along the skidroads. A study was installed to compare regeneration without disposal with windrow-burning and with slash removal, that is, piling it outside the strips. Much of the "piling" was accomplished by felling trees into the uncut stand. Windrow-burning did not consume all the wood, but needles and twigs were eliminated. Slash ratings showed that 42 percent of the no-disposal quadrats had heavy slash (over 60-percent cover) compared with 10 percent for the burned areas, and none on the slash-removed sections. Three seasons later both treatments had improved the distribution of new seedlings (table 5). On the no-disposal plots, stocking of new seedlings beyond the skidroads averaged 47.8 percent, compared with 59.6 percent where slash was burned, and 66.7 percent where slash was removed. On roads, it ran 94 to 100 percent for all treatments. Raw litter remained the seedbed on 28.5 percent of the no-disposal areas, 10.5 percent of the burned areas, and only 3.2 percent of the slash-removed areas.

For the treatments as a whole there were 2,933 seedlings per acre in the no-disposal areas, 4,333 in the windrow-burning, and 5,400 in the slash-removed areas. Counting all origins, there were 4,133 stems per acre on the no-disposal areas, 4,500 on the burned, and 6,016 on the slash-removed areas. These figures obscure distribution with respect to slash piles and skidroads, but still leave a margin in favor of disposal.

TABLE 5.—*Stocking of established new black spruce seedlings* [1] *on clear-cut strips 3 years after cutting, by slash treatment and degree of slash cover*

Slash treatment	Quadrats with less than 20-percent slash		Quadrats with over 20-percent slash	
	Relation to total	Stocked with established new seedlings	Relation to total	Stocked with established new seedlings
	Percent	*Percent*	*Percent*	*Percent*
None	48	86	52	36
Windrow-burned	61	78	39	52
Removed	95	79	5	0

[1] Basis, 180 milacres. "Established new seedlings" means thrifty seedlings in the 2- and 3-year classes.

Lopping and scattering slash or just lopping have been advocated, but a study by Roe (*21*) suggests that lopping is poorer than no disposal—probably because more seedbed is covered.

Fresh slash contains quantities of viable seed, but unfortunately much of it seems to be wasted. Schoenike and Hansen (*24*) found that viability of seed in 4-year-old slash was only 1 to 12 percent. They estimated that not over 5,000 good seed per acre remained. Much seed is evidently shed soon after logging when seedbeds under slash are poor. Some must be blown onto seedbeds, but one cannot expect much lateral transport of seed already near the ground.

On large clear-cut areas those portions beyond the seeding range of standing timber could benefit from disposal only by removal of slash from advance growth and from seedbed with seed on it. These gains might be offset by destruction of seed in the slash.

Slash disposal will seldom make the difference between success and failure, but where a seed source is kept, treatment decreases time needed for restocking and cuts down on patchiness. Without disposal, failed areas may still fill in eventually. On the Section 18 plots there was a substantial increase in stems for several slash treatments 5 years after cutting, but 17 years after logging these gains had been obliterated by subsequent regeneration. Shortening the rotation and more uniform stocking are the principal arguments for slash disposal.

Site Quality and Regeneration

The role of site must be better understood, for edaphic conditions are perhaps the principal factors that limit generalizations from studies such as this. Stratification of the Big Falls data by site quality classes (table 6) indicates that layers, mostly of advance origin, were more abundant on poor sites than on medium or good.

This fact, plus differences in seedling stocking, resulted in less regeneration on good and medium sites than on poor—a finding corroborated by Buckman and Schneider (*5*), and Schoenike and Schneider (*25*). Had the spread in site quality been wider, these differences would probably have been further amplified. Very poor stands on stagnant or muskeg sites are known to regenerate by layering to an even greater extent.

Table 6.—*Stocking of black spruce reproduction 4 to 6 years after cutting, by site class, origin, and intensity of cutting*

Intensity of cutting and spruce site class [1]	Quadrats stocked with—			Basis: quadrats
	Established new seedlings	All layers	All origins	
	Percent	*Percent*	*Percent*	*Number*
Heavy:				
Good	36. 4	14. 1	49. 5	206
Medium	40. 6	16. 9	52. 5	510
Poor	32. 8	29. 7	56. 2	64
Light and uncut:				
Good	13. 1	15. 5	29. 3	328
Medium	16. 5	27. 6	44. 3	492
Poor	14. 1	53. 2	61. 4	220

[1] Adapted from Fox and Kruse (*7*).

Site index is at present the only well-developed tool for classification of swamp spruce sites in Minnesota, but it leaves much to be desired. For example, the usual community on good sites at Big Falls was pure spruce with a lesser flora of feather mosses, *Sphagnum*, and *Ericaceae*. Dominant trees averaged 50 to 65 feet in height at 100 years. But spruce of equal site index also occurs where alder, sedge, ferns, and several herbs form the lesser flora. There tamarack (*Larix laricina*) and northern white-cedar (*Thuja occidentalis*) intergrade with spruce types. Buckman and Schneider (*5*) refer to the latter situations as "swamp margin good sites"—the class with poorest regeneration. LeBarron (*14*) also observed that tamarack sites are not easily maintained in spruce. At Big Falls only a small proportion of the study was in this alder-spruce-tamarack site group, but regeneration problems certainly are more complex there. It is doubtful that cutting systems and slash disposal alone will solve the problem. Yet this class of sites cannot be distinguished from less difficult good sites on a site index basis.

A new method of classifying bog sites is needed, based upon factors that actually cause site differences. Site studies now under way should help. It is already clear that certain popular theories are not adequate guides. Good spruce stands in the alder-spruce-tamarack site group are not invariably near the swamp margin, nor always on shallow peat.

Other Factors

Competition from labradortea, blueberries, cranberries, and other *Ericaceae* must be a factor in establishment of regeneration, but at Big Falls restocking was not closely related to density of these shrubs 4 to 6 years after logging. Stocking of established seedlings was 40.8 percent for the lowest shrub density class in the heavy cuttings, and 35.7 percent for the highest. If advance growth is added, stocking actually was greater at higher shrub densities. Of course, preexisting stand and shrub conditions could have influenced this outcome. Work by LeBarron (*14*) suggests that labradortea is a competitor.

In the Big Falls slash study, shrub cover increased rapidly after clear cutting. Only 2.8 percent of the quadrats had more than a 10-percent cover of *Ericaceae* after logging, but three seasons later 48.3 percent had an 11- to 35-percent cover, and 8.3 percent had more than 35-percent cover. If these plants do compete with spruce, the increase is an argument for prompt regeneration. According to Place (*20*), shrub cover seems to promote a loose, deep growth of *Sphagnum*, which is inimical to regeneration. The latter relationship was also noted at Big Falls.

Speckled alder, quaking aspen (*Populus tremuloides*), and raspberry (*Rubus* spp.) are abundant on some cuttings. Aspen seeds in over long distances from mineral soil areas, but is eventually outgrown by black spruce on most peat soils. Alder and raspberry may be competitors, but neither could be evaluated well at Big Falls. Established seedlings were rarely found in the few alder thickets on the study. Smothering of new seedlings by the annual leaf fall is one direct mechanism through which alder might compete.

Snowshoe hares (*Lepus americanus*) browse and debark seedlings and layers, although black spruce is not a preferred food (*1*). Hare damage is a factor contributing to the regeneration problem, especially on brushy sites where these animals often are abundant. Seed is destroyed by red squirrels (*Tamiasciurus hudsonicus*), and cone insects (*14*), and probably by birds and mice, but seed supplies are usually large despite these inroads.

Stand age probably has an effect on regeneration through its indirect influence on overstory density, seed yields, seedbeds, etc., but at Big Falls there was not a clear difference between age classes ranging from 70 to 180 years.

Effectiveness of the Cutting Systems

Let us now appraise the overall effectiveness of the alternative cutting systems in the light of the foregoing evidence. So far, one of the major differences between systems at Big Falls lies in the proportion of seedlings to layers (table 7). In the heavy cuttings all seedlings constitute 79 percent of the stems, while in the selection systems and light thinnings, seedlings make up only 47 percent.[7]

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[7] Stocking of new seedlings in the heavy cuttings was significantly higher than in the uncut plots by analysis of variance. This was not true of new seedlings in the selection systems and light thinnings.

Many layers in all systems were small, shrubby stems that had been present before cutting. This increase in seedling regeneration with heavy cutting is a strong point in favor of the even-aged systems. When all origins are considered, the systems do not differ so much, although there still were more stems in the heavy cuttings. It is too early to evaluate differences in height growth.

Table 7.—*Stocking of black spruce regeneration in the Big Falls compartment study 4 to 6 years after logging, by cutting systems and origin classes*

Cutting system	Quadrats stocked with—				Regeneration: trees per acre				Basis: mil-acre quadrats
	Established new seedlings [1]	All seedlings	All layers	All origins	New seedlings	All seedlings	All layers	All origins	
	Percent	*Percent*	*Percent*	*Percent*	*Number*	*Number*	*Number*	*Number*	*Number*
Clear-cut patches	50. 0	53. 3	18. 8	61. 7	2, 671	2, 933	796	3, 729	240
Clear-cut strips	28. 8	35. 0	17. 9	47. 5	1, 329	1, 704	475	2, 179	240
Shelterwood	38. 0	41. 0	15. 3	51. 3	1, 867	2, 207	593	2, 800	300
Group selection	16. 4	21. 6	12. 8	32. 4	576	756	492	1, 248	250
Tree selection	24. 7	25. 3	28. 7	48. 0	763	910	927	1, 837	300
Light thinning	10. 8	14. 6	30. 4	41. 5	388	565	1, 169	1, 734	260
Uncut	5. 7	7. 4	46. 5	49. 1	83	130	2, 261	2, 391	230

[1] "Established new seedlings" were thrifty seedlings at least 2 years old, of postcutting origin. For the uncut plots "new" means seedlings that became established since the original counts.

In even-aged management the old stands must be totally replaced through a system of removal cuttings. Decisions as to what constitutes adequate restocking, either in number of stems per acre, distribution, or time required are subjective, or could be arrived at only by a formal economic analysis. However, many foresters will accept 60-percent stocking, attained within about 5 years after cutting, as a fair standard for even-aged black spruce regeneration. If 60-percent stocking is accepted as the minimum for a full stand, then only the clear-cut patches met this objective after 4 to 6 years. About 3,500 trees per acre were required to attain 60-percent stocking with the patchy regeneration characteristic of these areas. Distribution could have been improved by slash disposal. Shelterwood cutting was almost as effective as patches, but the residual stands must still be removed before restocking can be fully evaluated. One may well ask why strip cutting produced less reproduction than patch or shelterwood cutting. Probable causes are the pattern of slash concentrations, plus possible site and seedbed differences. Overstories and proximity to seed sources were certainly similar to those in the patch cuttings. Success with clear-cut strips on the slash disposal study demonstrated that the system can be effective.

All-aged management requires only the replacement of cut trees with thrifty new stems. Since both selection systems at Big Falls have more small stems than the number of trees removed by logging, one might assume that these systems are successful. But the real test lies in bringing the trees through to harvest. Results on the Section 18 plots strongly suggest that this cannot be done. Evidently, residual stands must be cut far below the 76 to 87 square feet of basal area left in the selection compartments. If this is done, a shelterwood is created, and a full stand of even-aged seedlings can be expected. If the residual stand is not greatly reduced, regeneration will make little growth. Group selection might succeed if the openings are enlarged to the point where they approach patch clear cutting. The most promising situation for all-aged management is on poor sites. There, stands are open, layering is abundant, and only the largest trees are merchantable in any event.

The windfall hazard is frequently cited as a barrier to partial cutting and strip clear cutting in swamp spruce. Experience at Big Falls does not support this view. Only the shelterwood cuttings in tall old stands, exposed to the wind by open areas, have suffered serious losses (*10*).[8] Earlier work by LeBarron (*13*) also indicated that light partial cutting is feasible from the wind standpoint. The present study has not yet determined how far strip or patch clear cutting can be carried without damage, but the first cuts were certainly safe.

All factors considered, even-aged management seems to square best with research results, and to best fit the silvical characteristics of black spruce. Clear-cut patches and strips provide an open area in which regeneration can develop free of overstory competition, yet within seed dispersal range of uncut stands. Shelterwood cutting is effective, but involves greater risk of wind loss. Optimum width of strips or size of patches has not been determined. LeBarron's (*11*, *14*) seed-fall data suggest that strips up to 150 or 200 feet wide might receive enough seed, especially if some advance growth is present. Strips of this width are now being tried with burning of slash windrows (fig. 5). Both east-west and north-south orientation of strips have been used, but the effect of orientation remains uncertain.

"Rim cuts" are a modification of strips first proposed by Day (*6*). This system involves clear cutting a 50- to 100-foot swath along the stand edge (preferably to the leeward) and repeating the cut when the open area has restocked. If such a procedure is followed, regeneration success should approximate that obtained with clear-cut strips. At present rim-cutting is often employed as a salvage measure to clean up decadent old timber and deteriorating stand edges—conditions that are very common along swamp margins. While the real objective is salvage rather than regeneration, the effect of the operation on regeneration plans for the remainder of the swamp should also be considered. If the initial rim cut is made along the swamp

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[8] This does not necessarily mean that light partial cutting of swamp spruce will increase total pulpwood yields. That is a separate question still under study at Big Falls, and beyond the scope of this report.

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FIGURE 5.—A clear-cut strip where slash was windrow burned. Note ashes down center of strip. Burning done while peat was snow covered.

margin, and succeeding cuts simply taken from this retreating stand edge, the system tends to remove the best spruce first, because site quality usually decreases toward the swamp's center. This tendency toward high grading could easily be overcome by starting additional frontage areas on medium and poorer sites in the interior of the swamp.

There are so many sources of regeneration in swamps that the danger in cutting strips or patches somewhat larger than dictated by seed fall is not always great. Even really large clear-cut areas often restock through the fortunate combination of advance growth, seed on the ground, seed in slash, and subsequent seeding from the new stand. Unfortunately, the best stands tend to be the most difficult to reproduce. Advance growth is sparse, seedbeds are often poorer, the slash potential is great, and competition from other plants is apt to be keen. On the better sites especially, success is more likely if clear-cut areas are kept within seeding range, and heavy slash is

burned or removed. Where alder is abundant even these precautions may not suffice, and some combination of ground preparation, control of competition, or planting seems essential.

Summary

Black spruce (*Picea mariana* (Mill.) B.S.P.) occurs extensively in the peat bogs and swamps of northern Minnesota, where it is an important pulpwood tree. Natural regeneration is relied on, but a comprehensive test of possible cutting systems has not been reported. This report presents the first results of such a test on the Big Falls Experimental Forest, 4 to 6 years after the initial logging. A summary of the literature and of older station studies is included. The objective is not to prescribe techniques, but to explore the evidence and draw conclusions on silvicultural aspects. Application of this knowledge rests with land managers who will need to consider economic and other factors in addition to the questions discussed here.

At Big Falls the cutting systems under test include several approaches to both even-aged and all-aged management. The even-aged systems are clear cutting in strips, clear cutting in patches, and shelterwood cutting. All-aged management is being attempted with tree selection and group selection cuttings. There also are light thinnings and uncut check areas. From this project, and from previous work at the experiment station and elsewhere the following conclusions are drawn:

1. Overstories influence regeneration through their effect on heat, light, competition for water and nutrients, seedbed conditions, seed supplies, and other factors. Provided seed is available, the initial catch of seedlings can be good either in the open or beneath a moderate overstory, but subsequent survival and height growth are much better in the open.
2. Slow-growing *Sphagnum*, disturbed peat and moss on skidroads, and burned duff are good seedbeds. Feather mosses, *Dicranum*, and raw litter are poor. Fast-growing *Sphagnum* engulfs and kills seedlings.
3. Stocking of advance growth may vary from less than 10 percent to over 90 percent. Much advance growth is of layer origin, poor in form and vigor. Clear cutting destroys 30 to 50 percent of small advance stems. Advance reproduction should be regarded as an adjunct to new seedlings rather than a solution to restocking problems.
4. Slash covers seedbed with litter and buries advance growth when stands are clear cut. About 10 years are required for natural disappearance of slash. Stocking of new seedlings is closely related to slash density. Slash burning or removal increases seedbed area and improves seedling distribution when a seed source is retained. These practices shorten the period of restocking and thus the rotation.
5. Seedling establishment is best on medium sites. Poor sites restock well, but the proportion of layers is high. Restocking is poorest on good sites, but the class of good sites most difficult to restock was not common in this study. It seems to include communities where the lesser vegetation consists of alder, sedges, and ferns, rather than mosses and *Ericaceae*. Site index is not an adequate guide for dis-

tinguishing between these "most difficult" and "less difficult" good sites.

6. Competition from the *Ericaceae*, speckled alder, and raspberry has not been adequately assessed. Density of these shrubs increases rapidly after clear cutting.

7. All-aged management might succeed on poor sites where stands tend to be open and regeneration by layering is abundant. On better sites, the tree selection system is not promising because reproduction apparently cannot make satisfactory growth beneath the overstories that must be retained. Group selection may succeed if the stand openings are enlarged to the point where they approach patch clear cuttings. The Big Falls studies are not old enough to answer some of these questions.

8. Even-aged management is the most promising approach in swamps of the type studied. Systems of clear cutting in strips or in patches are effective because they provide an open area within seed dispersal range. When combined with slash burning or removal these systems permit the establishment of new seedlings, give maximum release to advance growth, and free the new generation from overstory competition. Shelterwood cutting is also effective, but more hazardous from the windfall standpoint. It seems clear that black spruce, growing in the swamp habitats of northern Minnesota, is adapted to even-aged management. It remains to be seen whether all-aged stands can also be developed.

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